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SIMULATOR SICKNESS AND ITS RELATIONSHIP TO OCULOMOTOR ACTIVITY – COMPARISONS OF A FIXED-BASE VS. FULL-MOTION SIMULATOR

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Introduction: Studies on simulator sickness take into account an increasing number of factors regarding individual characteristics (e.g., gender, age, experience), testing time as well as simulator testing conditions, to name a few. In addition to the symptoms of simulator sickness expressed at the level of subjective indicators, it is also important to consider physiological indicators. The present study was designed to test whether the use of a fixed-base vs. full-motion simulator influences the severity of simulator sickness symptoms and changes in the level of oculomotor variables.

Methods: Twelve male subjects with age M=29.8, SD=4.26 participated in this study. Each subject performed two 30-minute simulator tasks following the same route. Each of these tasks was performed in different configuration of a truck simulator manufactured by ETC-PZL Aerospace Industries: Condition 1 – fixed-base simulator, Condition 2 – full-motion simulator. Eye movements were recorded during the simulator task. Additionally, the SSQ questionnaire was filled out immediately after the simulator task and 1 h after leaving the simulator.

Results: The results show a higher level of most symptoms of simulator sickness under 2nd condition (full-motion simulator). In the case of measurement immediately after completing the task on the simulator, there was an increase in oculomotor problems. On the other hand, the measurement after 1 h also revealed a significant increase in nausea, oculomotor and disorientation. Moreover, after 1 hour, a relationship between nausea symptoms and oculomotor indices was found.

Tables: 4 • **References:** 13 • **Full-text PDF:** http://www.pjambp.com • • **Indexation:** Index Copernicus, Polish Ministry of Science and Higher Education

Discussion and Conclusions: Results indicate the influence of simulator testing conditions on the occurrence of simulator sickness symptoms. In addition, the relationship between variables measured by the oculograph and subjective symptoms of simulator sickness was demonstrated. The results obtained indicate changes in the sensitivity of physiological indicators and are discussed in the context of the possibility of using simulators in the diagnosis and training of selected functions.

Keywords: physiological variables, simulators, simulator sickness

INTRODUCTION

Simulators are becoming increasingly popular in driver and pilot training as well as in therapeutic processes. In addition to the undoubted advantages of using simulators, exposure to the conditions created in simulators is associated with the possibility of a number of ailments known as simulator sickness. Among the most commonly cited complaints of simulator sickness are nausea, headaches and disorientation. These ailments, despite the fact that they naturally subside over time, are undoubtedly a situation that requires control, understanding and consideration when using simulators. This happens for several reasons. Firstly, the symptoms of simulator sickness can interfere with the level of task performance in the simulator. Secondly, symptoms of simulator sickness can manifest as changes in physiological parameters and thus interfere with the measurement of physiological variables. It is important to remember that during testing in simulators, a number of physiological indicators are often recorded, which are later analyzed, for example, in the context of workload processes. Simulator sickness can affect the level of these indicators and thus prevent them from being interpreted as intended. Thirdly, simulator sickness can negatively affect, admittedly for a limited time, the performance of tasks in natural conditions [1].

Among the conditions of the simulator test, as a component with a potential impact on the severity of symptoms of simulator sickness, both those related to the motor stimuli generated by the platform's motion system and those related to the type of visual stimuli should be pointed out. For example, the team of Sharples et al. [11] conducted a study in which they decided to test if the severity of simulator sickness symptoms varied under different conditions of virtual reality (HMD). The results of the study showed that in 60 to 70 percent of cases, exposure to HMD was associated with an increase in symptoms of simulator sickness. Drexler [3], on the other hand, showed that when using a car simulator, the greatest discomfort was observed on the oculomotor disturbance dimension, followed by disorientation and the least on the nausea dimension (SSQ profile –Disorientation (D) > Oculomotor disturbances (O) > Nausea (N)).

In addition to the type of visual stimulus presentation, another factor considered in research on simulator sickness is the presence of a motor system responsible for generating motor stimuli (fixed-base platform vs. full-motion platform). In the case of testing in simulators with a fixed-base platform, movement information is provided to the examined person through visual information. Full-motion platforms, on the other hand, are used to increase the realism of the tests performed. In simulators of this type, motion information is provided through both visual and motor stimuli [12].

Curry et al. [2] decided to evaluate differences in the severity of simulator sickness between a fixed-base and a full-motion platform (Six degrees of freedom, 6 DOF). Analysis of the results showed that the severity of simulator sickness symptoms was higher for fixed-base platforms compared to full-motion platforms. In contrast, the profile of the individual SSQ subscales was the same in both cases (D>O>N). Other studies, on the other hand, indicate that when the perceived movement is based on visual stimuli alone, as is the case with fixed-base platforms, an increase in nausea in particular has been observed [7,8]. Stoner et. al. [12] also note that the use of full-motion platforms may not produce differences in the severity of simulator sickness compared to fixed-base platforms, or may even exacerbate the symptoms. Since the results of previous studies do not conclusively indicate whether the use of motion stimuli and under what conditions is a provoking factor in the onset of simulator sickness, research on the effect of the type of simulated motion on the symptoms of simulator sickness must continue [13].

Thus, in the study conducted in the paper, we were interested in:

1. whether the use of a full-motion vs. fixed-base platform in a simulator affects the severity of symptoms of simulator sickness;

2. whether the use of a full-motion vs. fixed-base platform in the simulator affects the oculomotor activity recorded during the test; and
3. whether changes in oculomotor activity are translated into subjectively perceived levels of simulator sickness.

METHODS

The participants in the study included 12 males aged M=29.8, SD=4.26. The examined persons had no prior experience in performing any tasks in simulators. The research has received approval from the Ethics Committee at the Military Institute of Aviation Medicine.

The study used a truck simulator manufactured by ETC-PZL Aerospace Industries [4]. The simulator was built on the basis of a fully equipped, air-conditioned cabin of a modern Mercedes-Benz Actros truck. The cabin was mounted on a full-motion platform with six degrees of freedom, making it possible to change the position of the simulator cabin along and around the longitudinal, transverse and vertical axes. The simulated image of the road environment was projected onto a cylindrical screen with a radius of 4.1 meters, a field of view of 180° horizontally and 40° vertically. The display frequency was 60 Hz. The image was located at a distance of 4.03 meters from the subject's head, in a straight line. The simulator made it possible to follow the selected driving route using an automatic transmission, and a system of cameras installed in the cabin allowed for real-time observation of both the road environment and the driver's behavior while driving. A detailed description of the simulator is provided in paper [4].

To investigate changes in oculomotor activity and their relationship to reported severity of simulator sickness symptoms, the following oculomotor indices were recorded using a JazzNovo oculograph (JAZZ-Novo Ober Consulting, Poznan, Poland) [9]:

- saccade duration – the time it takes for the eye to make a movement and switch from one fixation point to the next. It is assumed that during the movement of the eye its acceleration can be as high as 500 angular degrees per second, so as a rule the duration of a saccade is a few tens of milliseconds, not exceeding 100 ms. The median of all saccade times was used as an indicator of saccade time in the data analysis;
- fixation time – the time during which the examined person kept their eyes on a given element of the task;
- DSF indicator – a measure of the saccadic and fixation intensity (ISF), which describes the relationship between the sum of the times of all the saccades and the sum of the times of all fixations made during individual tasks. The DSF index, calculated from the time parameters of saccades and fixations, is expressed by the formula: DSF(i) = TS(i)/TF(i), where: TS – total duration of saccadic movements in the studied time interval; TF – total duration of fixations in the studied time interval; (i) – number of the studied sample.

Some studies indicate that reductions in ISF may be related to changes in the complexity of tasks performed and thus reflect the level of workload experienced by the examined person [6,10]. Very low ISF values (close to or reaching zero) may indicate "spacing out" or a mental blackout associated with CNS hypoxia, e.g., due to exposure to acute hypoxia or the action of overloads exceeding the system's compensatory capacity (these situations predominantly involve activities of a pilot). In turn, an increase in the ISF level may indicate an increase in visual data collection from the environment and, in the case of tasks performed in a simulator, a switch of attention between tasks presented in the central and the peripheral field of view.

The SSQ was used to assess the severity of simulator sickness symptoms, which is currently the most widely used measure for subjective assessment of simulator sickness symptoms [5]. The SSQ consists of four scales: nausea (N), oculomotor disturbances (O), disorientation (D) and SSQ score (T).

Procedure

Each subject performed two 30-minute simulator tasks, following the same route, under the same visual conditions. The only difference between the two studies was that one was performed with the motion platform turned off (fixed-base), while the other was performed with the motion platform running (full-motion). The conditions of the study were randomized. The severity of simulator sickness symptoms was measured at two points in time: 2 minutes after completion of the test in the simulator and 1h after completion of the test in the simulator. The measurement after 2 minutes was to refer to the direct effect of the test conditions in the simulator on the aspects under study and the measurement 1h after the simulator task was completed was to refer to deferred changes over time. Oculomotor activity was recorded continuously while performing the task in the simulator.

Statistical analysis

Changes in values in each of the four SSQ subscales (N, O, D and T) were analyzed using a Student's t-test, comparing data recorded during the experiment in a fixed-base and full-motion simulator. These tests were conducted separately for data recorded 2 and 60 minutes after the test in the simulator was completed. Secondly, the analysis was performed of correlation between SSQ values (N, O, D and T) and oculographic indicators (DSF indicator, fixation time and saccades duration). This analysis was carried out only for the full-motion simulator condition. The statistical package PASW 19 (formerly SPSS) was used for all analyses.

RESULTS

Table 1 shows the values of simulator sickness symptom severity and eye movement parameters during exposure in the simulator without a moving platform and with a moving platform. The values shown are for the measurement immediately after completing the task in the simulator, as well as those taken 1 h after completing the task in the simulator.

Pairwise comparisons for dependent samples between test conditions, at the point just after the task was completed, are shown in Table 2. As can be seen, a significantly higher level of visual impairment (oculomotor) was observed in the conditions of a full-motion platform p=0.023. On the other hand, for variables such as disorientation and total SSQ, higher values were observed for full-motion platform, but these differences take the value of statistical trend, p=0.075 for the disorientation variable and p=0.068 for the total SSQ.

The above comparisons concerned SSQ measurements taken just after the task was completed in the simulator. Since the SSQ measurement was also taken 1 h after the completion of the task in the simulator, pairwise comparisons for the dependent samples for this measurement are also shown below. As shown in Table 3, significantly higher levels of nausea-related disorders occur after performing a task in a simulator with a full-motion platform (p=0.01). Similarly, higher simulator sickness symptoms were found for oculomotor (p=0.07) and disorientation (p=0.06) symptoms.

The final element in the analyses of the results was to evaluate the relationship of the individual oculomotor indicators recorded under each test condition in the simulator and the SSQ values measured just after the task in the simulator and after 1 h. Detailed analysis data is presented in Table 4. It turns out that nausea symptoms correlate negatively with the value of the DSF indicator and

Table 1. Descriptive statistics for eye movement parameters and SSQ subscale values with measurement conditions.

Simulator configuration	Time of measurement	SSQ subscale	Descriptive statistics	
			M	SD
fixed-base platform	2 minutes after the task on the simulator	nausea	31.01	45.68
		oculomotor	27.16	33.50
		disorientation	40.60	68.31
		total SSQ	36.47	51.83
	1 h after the task on the simulator	nausea	13.52	18.84
		oculomotor	17.69	18.66
		disorientation	23.20	34.27
		total SSQ	20.26	23.94
	during the simulator test	DSF indicator	0.226	0.060
		saccades duration	66.95	6.203
		fixation time	314.09	76.22
full-motion platform	2 minutes after the task on the simulator	nausea	48.49	39.95
		oculomotor	53.69	35.03
		disorientation	71.92	63.61
		total SSQ	64.82	47.80
	1 h after the task on the simulator	nausea	28.62	21.91
		oculomotor	41.06	30.05
		disorientation	44.08	52.03
		total SSQ	43.32	35.85
	during the simulator test	DSF indicator	0.228	0.041
		saccades duration	67.08	4.044
		fixation time	301.78	42.16

Table 2. Comparisons of SSQ values measured immediately after completion of the task in the simulator depending on the type of simulator (fixed-base vs full motion simulator).

SSQ subscale	Simulator configuration	M	SD	t value	p (one tailed)
nausea	fixed-base	31.00	45.68	-1.04	.160
	full motion	48.49	39.95		
oculomotor	fixed-base	27.16	33.51	-2.23	.023
	full motion	53.69	35.03		
disorientation	fixed-base	40.60	68.31	-1.47	.075
	full motion	71.92	63.61		
total SSQ	fixed-base	36.47	51.82	-1.61	.068
	full motion	64.82	47.79		

Table 3. Comparisons of SSQ values measured 1 h after completion of the task in the simulator depending on the type of simulator (fixed-base vs full motion simulator).

SSQ subscale	Simulator configuration	M	SD	t value	p (one tailed)
nausea	fixed-base	13.52	18.84	-2.65	0.01
	full motion	28.62	31.91		
oculomotor	fixed-base	17.69	18.66	-2.88	0.07
	full motion	41.06	30.05		
disorientation	fixed-base	23.20	34.27	-1.66	0.06
	full motion	44.08	52.03		
total SSQ	fixed-base	20.26	23.95	-2.55	0.13
	full motion	43.32	35.85		

Table 4. Summary of the analysis of correlation between SSQ values and oculographic indicators (full motion simulator).

Time of measurement	SSQ subscale	DSF indicator	saccades duration [s]	fixation time [s]
immediately after driving	nausea	-.403	-.293	.423
	oculomotor	-.212	-.126	.276
	disorientation	-.343	-.201	.418
	total SSQ	-.331	-.213	.388
1 h after driving	nausea	-.588*	-.436	.695*
	oculomotor	-.332	-.222	.451
	disorientation	-.261	-.153	.397
	total SSQ	-.380	-.256	.508

positively with average fixation time. These relationships apply only to full-motion conditions and the measurement of SSQ 1 h after the completion of the task in the simulator.

DISCUSSION AND CONCLUSION

The results of the present study indicate that a significantly higher severity of simulator sickness symptoms related to oculomotor disturbances was observed in full-motion conditions. However, in the case of disorientation and total result, the differences were at the level of statistical trend, also indicating an increase in symptoms when using the full-motion platform. It is worth noting the differences in symptoms of simulator sickness between the full-motion and fixed-base platforms 1 h after the completion of the simulator task. It turns out that at that time both symptoms determined on the oculomotor, nausea and disorientation scales had significantly higher levels after exposure to full-motion conditions compared to fixed-base conditions. Simulator sickness profiles for both platforms were similar and expressed as follows: D>O>N. Only in the case of fixed-base platforms immediately after the examination, the simulator sickness profile was D>N>O. This may mean that the changes in nausea were more abrupt while in oculomotor disturbances they persisted for a longer period of time. In contrast, the severity of disorientation symptoms was highest in the context of both measurement time and the type of platform used. Among a number of oculographic indicators, the mean fixation time as well

as the value of the DSF index were significantly associated with nausea symptoms. This relationship was only related to the measurement of nausea 1 h after completing the task in the simulator.

In summary, the results of the presented study confirm that simulator sickness can be a significant problem in the use of simulators, as expressed in the severity of nausea, disorientation and oculomotor complaints. It is widely accepted that the use of a full-motion platform can, by better reflecting natural conditions, reduce the symptoms of simulator sickness and increase the realism of the tasks performed. The results obtained in this study indicate that in conditions with a full-motion platform, not only is an increased severity of symptoms of simulator sickness observed, but also that this may be related to changes in oculomotor activity during simulator tasks. Thus, the introduction of a full-motion platform can be an additional source of conflict at the level of perceived stimuli. Similar problems are pointed out by Stoner et al. [12].

AUTHORS' DECLARATION:

Study Design: Marcin Biernacki. **Data Collection:** Marcin Biernacki. **Manuscript Preparation:** Marcin Biernacki. The Author declares that there is no conflict of interest.

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